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INHERITANCE OF NUMBER OF SEEDS PER POD AND LEAFLET SHAPE IN THE SOYBEAN [1]

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INTRODUCTION

Number of seeds per pod has been shown by Woodworth (*11*)[3] to be one of the several characters which contribute to yield of seed in the soybean (*Soja max* (L.) Piper). A clear understanding of the inheritance of these characters, as well as of the relations between them, is necessary in order to ascertain more accurately the possibility of obtaining all of them in the highest degree in one variety. This paper reports a study of the inheritance of number of seeds [4] per pod and leaflet shape. The latter character was included because of certain evidences of linkage between it and number of seeds per pod.

Soybean pods contain from one to five seeds. Plants of a given strain have either a majority of one-, two-, three-, or four-seeded pods or large percentages of any two consecutive classes from one to four. Strains with a majority of one-seeded pods are referred to in this paper as one-seeded strains, those with a majority of two-seeded pods as two-seeded strains, etc.

The terminal leaflet of most soybean varieties is ovate in shape; a few varieties have lanceolate leaflets, and one variety is known with oval leaflets (fig. 1). The lateral leaflets, although of the same general shape as the terminal leaflets, are somewhat asymmetrical and therefore have not been considered in this study.

REVIEW OF LITERATURE

Nagai (*3*) reported a cross between the three-seeded variety, Kaimame, and the two-seeded variety, Akutsuka. Approximately 70 percent of the pods of the F_1 were two-seeded, and about 70 percent of the F_2 plants resembled the two-seeded parent.

Data through the F_4 generation are presented by Takahashi (*6*) on a cross between Wearucong, a two-seeded variety with normal leaflets, and Yanta, a three- and four-seeded variety with narrow leaflets. A good fit to a 3:1 ratio for number of seeds per pod was obtained when the F_2 plants were divided into two classes according to whether less than 10 percent or more than 10 percent, respectively, of the pods from a given plant were four-seeded. Takahashi con-

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[2] The writer wishes to express his appreciation for the helpful advice and suggestions of Dr. C. M. Woodworth during the course of these investigations.

[3] Italic numbers in parentheses refer to Literature Cited, p. 267.

[4] Includes aborted seeds and aborted or unfertilized ovules since these were considered potential seeds.

cluded that the parents differed by a single gene and assigned to that allelomorphic pair the symbols *F* and *f*. The F_2 segregated in a 3:1 ratio of normal- to narrow-leaflet plants as Takahashi and Fukuyama (*7*) and Woodworth (*11*) had noted. Takahashi and Fukuyama (*7*) assigned the symbols *Na* and *na* to the allelomorphic genes involved. Linkage between narrow leaflet and high seeds-per-pod value was apparent in the F_2 and later generations, and the ratios obtained could be explained on the basis of 10 percent crossing over.

MATERIALS AND METHODS

The mean seeds-per-pod values of parental types available for crosses in this study ranged from 1.05 ± 0.01 for type 122 [5] to 3.59 ± 0.03 for type 114. With the exception of types 114, 122, 173, and 174, all of the types had seeds-per-pod means which tended to be somewhat intermediate between the extreme types, yet all of these means differed

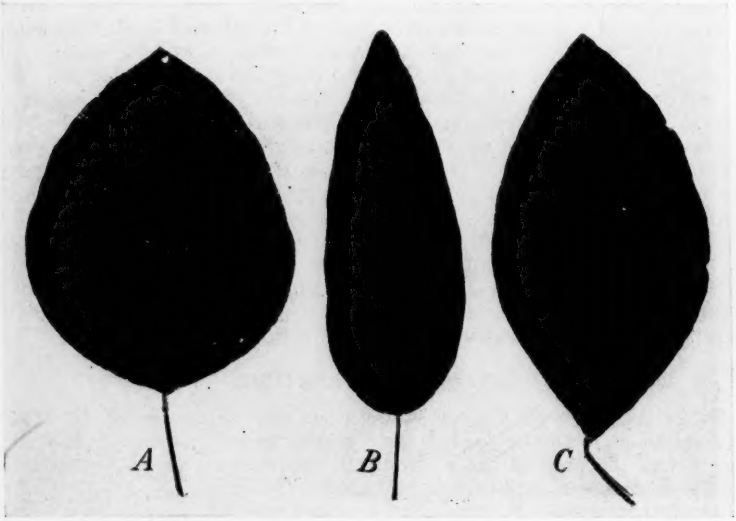

FIGURE 1.—Terminal leaflets of soybean plants: *A*, ovate or normal; *B*, lanceolate or narrow of types 114, 173, and 174; and *C*, oval of type 122.

significantly one from the other. These types are all classed as intermediate in this report. Types 173 and 174 had seeds-per-pod means which approached that of type 114. Types 114, 173, and 174 were therefore classed as high in seeds-per-pod value. Type 122 was classed as low. All of the intermediate types had normal leaflets, all of the high types had narrow leaflets, and the low type had oval leaflets.

Twenty crosses and six of their reciprocals were carried through the F_2 generation. Individual plants of the parental, F_1, and F_2 populations were classified for seeds-per-pod value and leaflet shape. A few progenies from two crosses were carried through F_3. Most of the F_1

[5] In accordance with Illinois Agricultural Experiment Station procedure, the strains used as parents have each been given a type number and the crosses have each been given a cross number.

values were obtained from plants grown under greenhouse conditions in gravel subirrigated with a nutrient solution. Because of the unusual environment in which these F_1 plants were grown, their seeds-per-pod values are not considered comparable to the parental and F_2 values obtained from field-grown plants.

The seeds for the F_2 were spaced at 4-inch intervals in consecutive rod rows 2 feet apart. Each F_2 population was bordered on one side by one row of one parent and on the other side by one row of the other parent. After harvest all pods were pulled from the plants and the number of one-, two-, three-, four-, and five-seeded pods was recorded for each plant. The number of potential seeds for each plant was obtained by summating the number of one-seeded pods multiplied by one, the number of two-seeded pods multiplied by two, etc. A seeds-per-pod value for each plant was calculated by dividing the total number of potential seeds by the total number of pods.

Leaflet-shape classifications of all populations were made by observation when the plants had reached approximately their maximum height. Difficulty was encountered in classifying some of the F_2 segregates. Several measurements were made on leaflets of parental and F_2 plants. Since the parents differed significantly in shape indices it was expected that the F_2 frequency distributions of these indices would be discontinuous and therefore classification would be facilitated. The measurements were made on five different terminal leaflets of each plant of the population at approximately equal intervals from the base of the plant to the top. The indices obtained on parental types and their F_2 generations segregating for leaflet shape were (1) the width of the leaflet at its widest point divided by its length, (2) the distance from the base of the leaflet to its widest point divided by its total length, and (3) the size of the angle formed by the two margins of the basal portion of the leaflet. The five values obtained on one plant for one index were averaged to give one index for the plant.

Twenty-five seeds from each of 25 plants were selected at random from the F_2 of a cross of intermediate-normal $\times$ high-narrow, along with 25 seeds of each parent. The seeds were planted in the manner described above to permit study of F_3. Seeds-per-pod and leaflet-shape classifications were made on these populations. Correlation coefficients between seeds-per-pod values of F_2 plants and their corresponding F_3 means and coefficients of variability were calculated.

Additional data on the inheritance of leaflet shape were obtained from 20 F_3 progenies from 12 narrow-leaflet and 8 oval-leaflet segregates of a narrow $\times$ oval cross.

Several of the F_2 populations yielded data for linkage tests between leaflet-shape genes and genes for other qualitative characters.

Since no difference between reciprocal crosses could be detected in any case, the data for reciprocals were combined for analysis and the two crosses identified as one. For example, crosses 516 and 524 were reciprocal crosses and are identified together as 516-524.

INHERITANCE OF NUMBER OF SEEDS PER POD

The relative constancy of seeds-per-pod values within a variety suggests that the character is governed largely by genic action. Weatherspoon and Wentz (*9*) counted seeds in 5 pods from each of 2 plants from 10 replications of 237 varieties. From the amount

of variance due to replications they concluded that the number of seeds per pod was influenced only slightly by soil differences. However, certain of the data obtained in the current study indicate that the character is not wholly uninfluenced by environmental factors. The planting of parental varieties in close proximity to each of their F_2 progenies necessitated planting 9 of the 11 varieities at more than one location in the field. Types 34, 38, 48, 114, 141, and 173 occurred twice in the field, type 10 occurred 3 times, and types 122 and 174 each occurred 4 times. When the *t* test was applied to all possible comparisons between seeds-per-pod means of the different plantings of each variety, 6 of the 21 mean differences were found to be significant at the 5-percent level. The significant differences were between the means of the 2 plantings of types 34, 38, and 114, and between 1 planting of type 122 and the other 3 plantings of type 122.

INTERMEDIATE × LOW

Four F_2 populations were derived from crosses between the one-seeded strain and the strains with intermediate values. Their F_2 frequency distributions were strikingly similar. Figure 2 shows the parental and F_2 distributions of cross 500, which is typical of this type of cross.

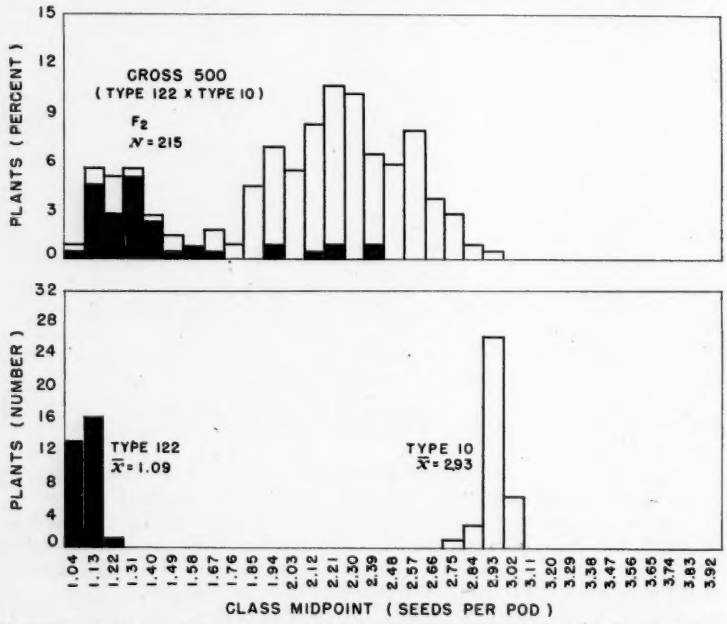

FIGURE 2.—Histograms of parental and F_2 seeds-per-pod distributions of cross 500, typifying those crosses between type 122, which had a low seeds-per-pod mean and oval leaflets, and types with intermediate seeds-per-pod values and normal leaflets. Shaded areas indicate the number of plants within each class which were classified by observation as oval-leaflet type.

The following characteristics were common to most of the F_2 distributions: (1) Certain segregates had values equal to the mean values of both parents; (2) no suggestion of transgressive segregation was apparent; (3) distinct bimodality was exhibited, with the larger portion of the curve comopsed of plants with the higher values; and (4) the modal value of the larger portion of the curve was lower than the mean of the higher parent, and the modal value of the smaller portion of the curve was higher than the mean value of the lower parent.

The bimodality of the F_2 distributions suggested the action of relatively few genes. In all cases the number of segregates in the larger and the smaller portions of the F_2 curve showed a good fit to a 3:1 ratio. The data for the χ^2 tests are shown in table 1.

TABLE 1.—F_2 segregates of 4 intermediate × low seeds-per-pod crosses, showing segregation in a 3 : 1 ratio of intermediate- to low-value plants. Data for each cross are the numbers of plants in the larger and smaller portions of the bimodal F_2 histograms

Cross	Seeds-per-pod class		χ^2
	Intermediate	Low	
497	90	19	3.33
508	139	39	.91
504	70	18	.97
500	167	48	.82
Total			[1] 6.03

[1] P=0.10–0.20.

INTERMEDIATE × HIGH

F_2 populations were drived from 12 intermediate × high crosses. The histograms of crosses 511–523 and 516–524 are shown in figures 3 and 4 typifying the distributions obtained from this type of cross. Seeds-per-pod values of certain F_2 segregates of each cross were equal to the means of both of their respective parents except that in cross 511–523 no F_2 plant was as high in seeds-per-pod value as the mean of the higher parent. The difference between the parents of this cross was the greatest of the 12 crosses, and over 10 percent of the F_2 segregates fell within the range of the higher parent. In all crosses the seeds-per-pod value of the modal class of the F_2 distribution was only slightly higher than the mean of the intermediate parent and was very nearly the same as the mean of the few F_1 plants grown in the field the same season.

The F_2 distributions of three crosses, including 511–523, exhibited a tendency toward bimodality with high values constituting the smaller portion of the curve. These three F_2 distributions showed a good fit to a 3 : 1 ratio. The data are presented in table 2.

TABLE 2.—*F_2 segregates of the three intermediate × high seeds-per-pod crosses, including cross 511–523 shown in figure 3, which exhibited a tendency toward bimodality. The segregates fit a 3:1 ratio of intermediate to high values*

Cross	Seeds-per-pod class		χ^2
	Intermediate	High	
529	146	44	0.03
511–523	150	52	.06
527	49	10	2.04
Total			[1] 2.13

[1] P=0.05–0.07.

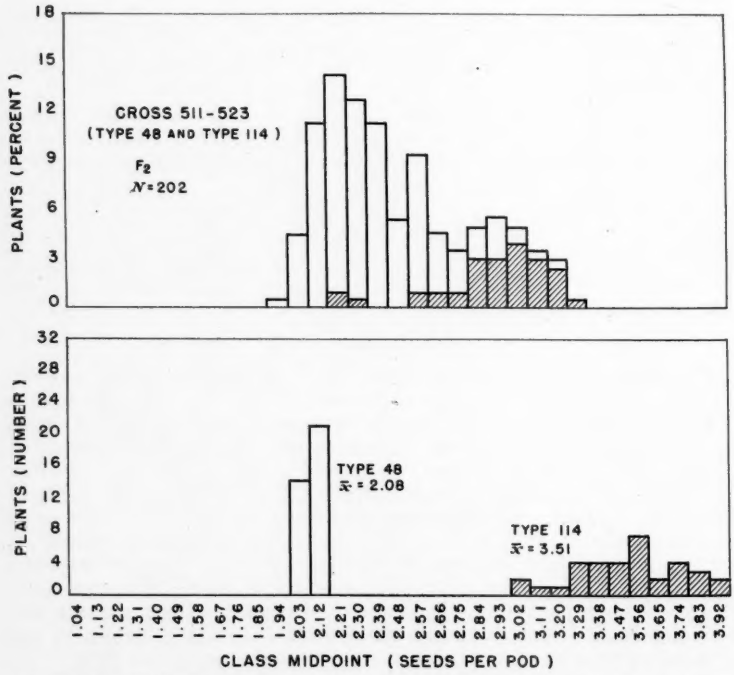

FIGURE 3.—Histograms of parental and F_2 seeds-per-pod distributions of cross 511–523. Cross-hatched areas indicate the number of plants within each class which were classified by observation as narrow-leaflet type.

INTERMEDIATE × INTERMEDIATE

Eight crosses were made between parental types with intermediate seeds-per-pod values. F_2 histograms of two of those crosses are shown in figures 5 and 6. In four of the crosses the F_2 means were intermediate between the parental means; in two crosses the F_2 means approached the means of the higher parents; and in two the F_2 means approached the means of the lower parents. Of the several

crosses studied, cross 159–160 produced the most nearly normal distribution. It is worthy of note that no hint of transgressive segregation was evident in this cross, even with 294 F_2 individuals from parents with quite similar mean values.

Significant positive correlations of 0.65, 0.52, 0.68, and 0.70 were obtained for four crosses when F_2 seeds-per-pod values were correlated with the seeds-per-pod means of their respective F_3 progenies.

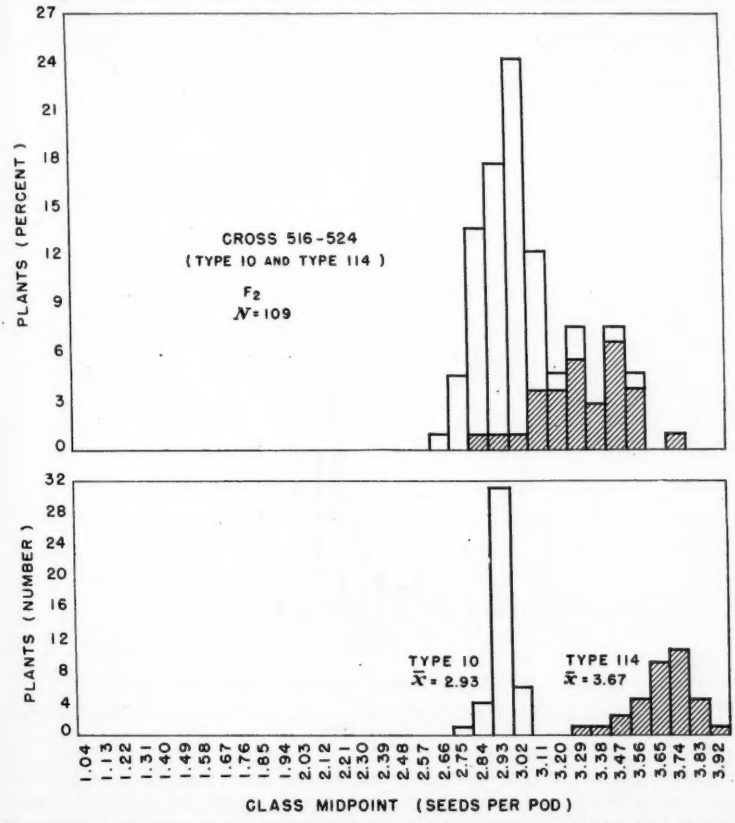

FIGURE 4.—Histograms of parental and F_2 seeds-per-pod distributions of cross 516–524. Cross-hatched areas indicate the number of plants within each class which were classified by observation as narrow-leaflet type.

A negative, but not significant, correlation coefficient of 0.36 was obtained when 22 F_2 seeds-per-pod values of cross 480 were correlated with the coefficients of variability of their respective F_3 progenies. An r value of 0.42 would have been significant at the 5-percent level of probability. A significant negative correlation between F_2 seeds-per-pod values and F_3 coefficients of variability would be considered

evidence that F_2 plants with high seeds-per-pod values were more nearly homozygous for seeds-per-pod genes than those with intermediate values.

LOW × HIGH

The parental and F_2 distributions of cross 522 are shown in figure 7 to represent the two low × high crosses. In both crosses (1) there were no segregates with values equal to the mean of either parent, (2) the value of the modal class of the F_2 distribution was slightly below

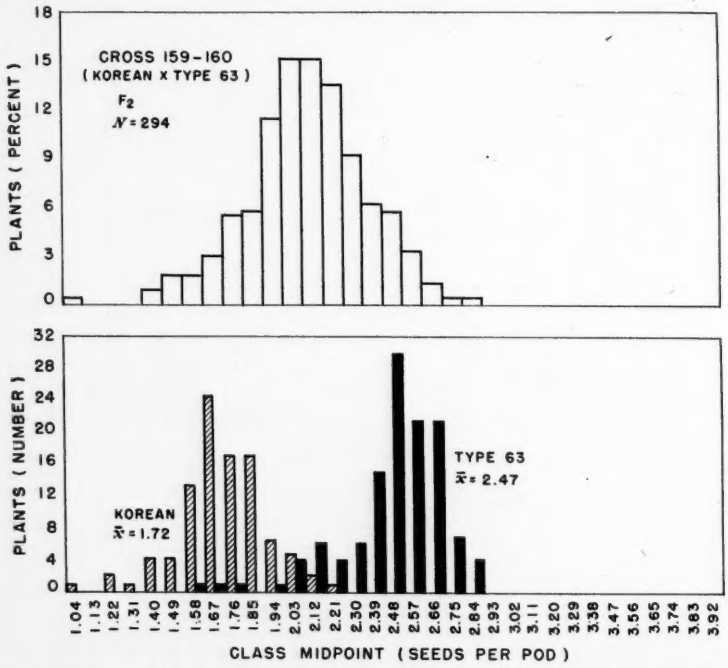

FIGURE 5.—Histograms of parental and F_2 seeds-per-pod distributions of cross 159–160.

the average of the two parents, and (3) both of the F_2 distributions showed a bimodal tendency, with approximately 13 percent of the segregates with the lower value constituting the smaller portion of the curve.

INHERITANCE OF LEAFLET SHAPE

NORMAL × NORMAL

The F_1 and F_2 populations derived from crosses between parents with normal leaflets consisted only of plants with normal leaflets.

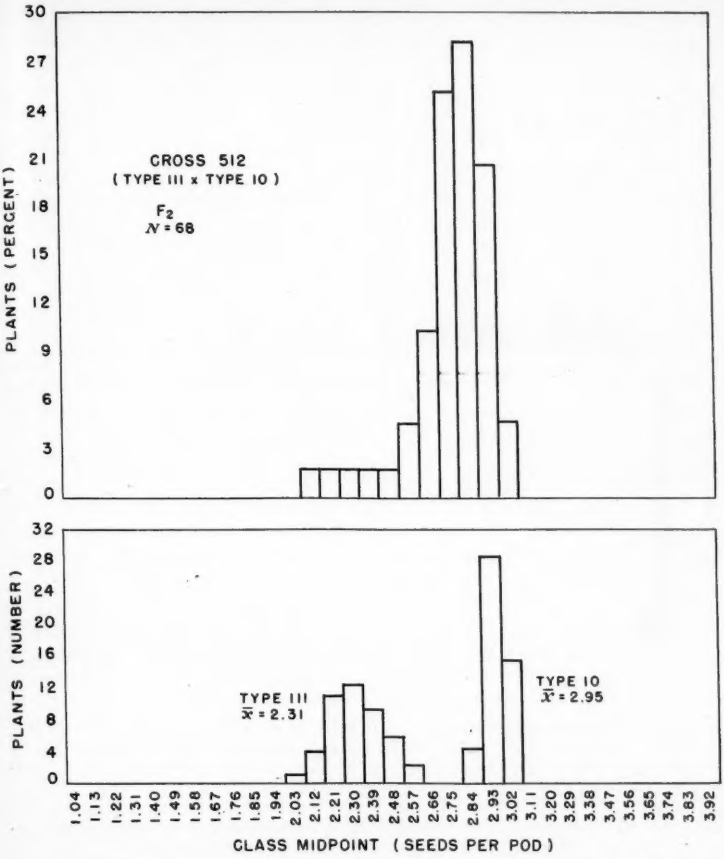

FIGURE 6.—Histograms of parental and F_2 seeds-per-pod distributions of cross 512.

NORMAL × NARROW

From 13 normal × narrow crosses 31 F_2 populations were grown and classified by observation with respect to leaflet shape. Only normal- and narrow-leaflet types were observed in the progenies, although a few types which were classified as normal appeared to approach an intermediate condition. The ratios of normal to narrow plants obtained was, in each case, a good fit to a 3:1 ratio (table 3).

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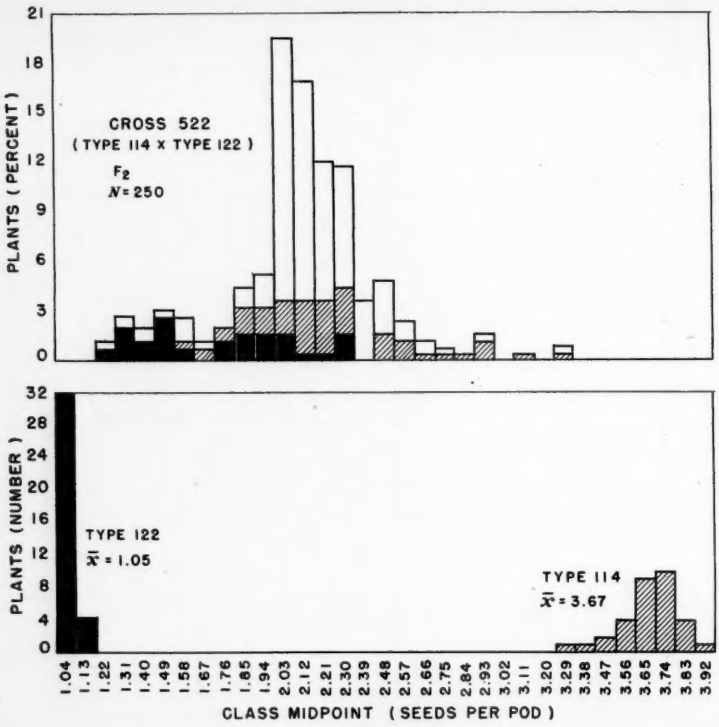

FIGURE 7.—Histograms of parental and F_2 seeds-per-pod distributions of cross 522. Shaded, unshaded, and cross-hatched areas indicate the number of plants within each class which were classified by observation as oval-leaflet, normal-leaflet, and narrow-leaflet types respectively.

TABLE 3.—*F_2 segregates of normal-leaflet × narrow-leaflet crosses, showing segregation in a 3:1 ratio of normal- to narrow-leaflet plants*

F_1 plant No.	Leaflet shape of F_2 plants		χ^2	F_1 plant No.	Leaflet shape of F_2 plants		χ^2
	Normal	Narrow			Normal	Narrow	
503A	6	3	0.333	523E	10	1	1.485
503B	8	4	.444	523F	44	9	1.818
503C	40	17	.708	524C	81	20	1.455
503D	8	4	.444	527	42	17	.458
503E	37	9	.725	528	12	4	.000
507A	128	40	.127	516	38	17	1.024
507B	4	2	.222	524A	2	2	1.333
507C	7	1	.667	524B	37	13	.027
507D	9	4	.231	520A	24	7	.097
511A	30	10	.000	520B	15	3	.667
511B	91	21	2.333	529A	14	3	.490
511C	55	17	.074	529B	3	0	1.000
521B	39	11	.240	529C	129	41	.071
523A	56	14	.933	525	42	15	.053
523B	7	1	.667				
523C	3	3	2.000	Total			[1] 20.496
523D	70	20	.370				

[1] P=0.90–0.95.

Of the 22 F_2 plants selected at random from cross 480, 6 had narrow leaflets and bred true for narrow leaflets in F_3. Of the 16 with normal leaflets in F_2, 6 bred true for normal in F_3 and 10 segregated in 3:1 ratios of normal to narrow. The 6:10:6 ratio is a good fit to the theoretical 1:2:1.

NORMAL × OVAL

Eight normal × oval crosses produced 23 F_2 populations which segregated for normal and oval. When the ratios were tested against a theoretical ratio of 3 normal to 1 oval the total χ^2 value exceeded that which corresponds to the 1-percent level of probability (table 4). Of the 21 populations, however, 18 had P values above 5 percent. The P value of the group as a whole was lowered by the large χ^2 values of 5 populations. Those 5 populations were from 2 F_1 plants of cross 508 and 3 F_1 plants of cross 515. The following facts suggest that these are chance deviations: (1) Another F_1 plant of cross 508 produced an F_2 segregation which fit the hypothesis, (2) crosses 515 and 508 were reciprocals of crosses 500 and 498 respectively, the F_2's of which fit the hypothesis, and (3) as regards the leaflet-shape gene, cross 515 is probably the same as cross 655, which fitted the hypothesis, since the pistillate parent of cross 655 was a chlorophyll-deficient mutation from the pistillate parent of cross 515.

TABLE 4.—*F_2 segregates of crosses between normal-leaflet and oval-leaflet parents, and χ^2 values when the segregates were tested to a 3:1 ratio*

F_1 plant No.	Leaflet shape of F_2 plants		χ^2	F_1 plant No.	Leaflet shape of F_2 plants		χ^2
	Normal	Oval			Normal	Oval	
497	86	23	0.884	655A	247	67	2.246
498	47	17	.083	655B	198	60	.419
500A	57	10	3.627	655C	123	34	.936
500B	9	0	3.000				
500C	73	21	.355	Subtotal			[1] 24.271
500D	4	3	1.190				
500E	21	6	.111	508B [2]	145	33	3.963
500F	1	2	2.778	508C [2]	64	7	8.681
500G	6	2	.000	515A [3]	75	11	6.837
502	28	10	.035	515B [3]	94	13	9.424
504A	49	9	2.782	515C [3]	115	18	9.326
504B	8	0	2.667				
504C	17	5	.061	Subtotal			[4] 38.231
504D	39	19	1.862				
508A	84	35	1.235	Total			[4] 62.502

[1] P=0.10–0.20.
[2] Reciprocal of cross 498.
[3] Reciprocal of cross 500; same as cross 655.
[4] P=<0.01.

NARROW × OVAL

The seven F_1 plants from two narrow × oval crosses had normal leaflets. The F_2 progenies contained plants which had either normal, narrow, or oval leaflets. The data presented in table 5 show χ^2 values obtained when the F_2 ratios were tested against a theoretical ratio of nine normal: three oval: four narrow. The P value lies between 50 and 70 percent.

TABLE 5.—*F_2 segregates of narrow-leaflet × oval-leaflet crosses showing segregation in a 9:3:4 ratio of normal- to oval- to narrow-leaflet plants*

F_1 plant No.	Leaflet shape of F_2 plants			χ^2
	Normal	Oval	Narrow	
501A	41	17	14	1.802
501B	5	1	1	.682
522A	32	8	14	.552
522B	76	25	29	.506
522C	33	6	11	2.240
522D	5	0	0	3.889
522E	8	1	2	1.283
Total				[1] 10.954

[1] P=0.50–0.70.

F_3 populations were grown from 12 narrow-leaflet F_2 segregates of a narrow × oval cross. Only narrow-leaflet plants were observed in these populations.

F_3 populations were grown from eight oval-leaflet segregates of the above cross. Three of the eight F_3 populations produced only oval-leaflet plants; the remaining five segregated in a 3:1 ratio of oval to narrow (table 6).

TABLE 6.—*Segregates of F_3 populations grown from 8 oval-leaflet F_2 plants of a narrow × oval cross, showing no segregation in 3 populations and a 3:1 segregation of oval to narrow in 5 populations*

Identity of F_3 population	Leaflet shape of F_3 plants		χ^2 (3:1)	P
	Oval	Narrow		
677A15	21		7.000	0.01
677A16	15		5.000	.02–.05
677A20	15		5.000	.02–.05
677A13	22	5	.605	.30–.50
677A14	16	6	.061	.80–.90
677A17	3	2	.600	.30–.50
677A18	1	1	.667	.30–.50
677A21	18	4	.545	.30–.50

LEAFLET INDICES

The parents which were used in the various leaflet-shape crosses differed markedly in the dimensional relationships of their leaflets as evidenced by their frequency distributions for each index. For an index to be of value in the classification of difficult plants, the F_2 distribution of the index should be completely discontinuous; that is, the index for a particular segregate must fall clearly into one or another portion of the F_2 distribution. Such was not the case when any of the indices were applied to any of these crosses. Some of the F_2 segregates, probably the same ones that caused difficulty in classification, fell between the two well-defined portions of the F_2 distribution. None of the indices used seemed, therefore, to be of value in making leaflet-shape classifications.

LINKAGE OF LEAFLET SHAPE AND SEEDS PER POD

If genes for number of seeds per pod were independent of genes for leaflet shape, it would be expected that each seeds-per-pod class of F_2 populations segregating in a 3:1 ratio for leaflet shape would

consist of normal-leaflet plants and oval- or narrow-leaflet plants in approximately a 3:1 ratio. That such is not the case is shown by histograms in figures 2, 3, and 4.

There was a tendency, shown in figure 2, for oval-leaflet segregates from all crosses involving type 122 (one-seeded type with oval leaflets) to have a low seeds-per-pod value. Such a tendency suggests linkage of the recessive gene for oval leaflet-shape with a recessive major gene for the low seeds-per-pod character, on the assumption that the seeds-per-pod character is governed by the combined action of a few major genes and several modifying genes. An indication of linkage intensities was obtained. All normal-leaflet plants having a low seeds-per-pod value and all oval-leaflet plants having intermediate seeds-per-pod value were considered as cross-over types. By this method cross-over percentages of 4.7, 5.1, 6.1, and 10.3 were obtained for crosses 497, 508, 504, and 500 respectively, or 7.9 ± 0.8 percent when the calculations were based on the totals for the four crosses. The ratios are presented in table 7.

TABLE 7.—*F_2 ratios and cross-over percentages between the loci of a major seeds-per-pod gene and the oval-leaflet gene for 4 crosses between type 122, with a low seeds-per-pod value and oval leaflets, and types with intermediate seeds-per-pod values and normal leaflets.*

Cross No.	Leaflet shape according to seeds-per-pod class				Cross-over percentage and probable error
	Intermediate		Low		
	Normal	Oval	Normal	Oval	
497	85	5	1	18	4.7±1.4
508B	137	2	8	31	5.1±1.2
504 ABC	69	1	5	13	6.1±1.8
500	159	8	12	36	10.3±1.5
Total	450	16	26	98	7.9± .8

All of the F_2 distributions from the crosses involving type 114 or type 174 (narrow leaflets and high seeds-per-pod values) showed a tendency for narrow-leaflet segregates to have high seeds-per-pod values, as is shown in figures 3 and 4. Such a tendency suggests linkage of the recessive gene for narrow leaflet shape with a recessive major gene for the high seeds-per-pod character. Since not all of these F_2 distributions produced a bimodal F_2 histogram, an estimate of the linkage intensity is not possible for all of them in the manner described above. However, when the method above was applied to those crosses which show the bimodal tendency (529, 511–523, and 527) cross-over percentages of 4, 13, and 13, respectively, were obtained or 9 percent when applied to the totals for the three crosses.

LINKAGE OF LEAFLET SHAPE AND OTHER QUALITATIVE CHARACTERS

LEAFLET SHAPE AND FLOWER COLOR

Flower color is governed by the allelomorphic genes W_1w_1 for purple and white (*2*). The F_2 ratios obtained indicate that the flower-color genes are not linked with leaflet-shape genes (table 8).

When its fit to a 9:3:3:1 ratio was determined, a narrow-white × normal-purple cross had a P value of 0.50–0.70. An oval-white × normal-purple cross produced an F_2 ratio with a P value of 0.50–0.70.

TABLE 8.—*F_2 and F_3 segregations and their respective χ^2 and P values for several crosses between parents differing in leaflet shape and other qualitative characters, showing independence of the genes involved*

Characters	*XY*	*Xy*	*xY*	*xy*	X^2	*P*
Narrow leaflet (*na*) vs. white flowers (w_1)	30	9	10	1	1.627	0.50–0.70
Oval leaflet (*o*) vs. white flowers (*w*)	30	9	15	4	2.138	.50– .70
Narrow leaflet (*na*) vs. gray pubescence (*t*)	26	13	5	5	4.805	.10– .20
	55	22	19	13	6.490	.05– .10
Oval leaflet (*o*) vs. gray pubescence (*t*)	67	18	19	4	2.091	.50– .70
Narrow leaflet (*na*) vs. fasciation (*f*)[1]	10	4	3	1	.173	.98– .99
	5	2	2	0	.679	.80– .90
	9	4	2	1	.667	.80– .90
	14	2	2	0	3.728	.20– .30
	11	5	2	2	1.689	.50– .70
	12	5	.5	0	1.758	.50– .70
Narrow leaflet (*na*) vs. yellow seed-coat color (*g*)	66	15	20	0	8.677	.02– .05
Components—*Nana* segregation					1.455	.20– .30
Components—*Gg* segregation					5.548	.01– .02
Components—Linkage					1.673	.10– .20
Oval leaflet (*o*) vs. unrestricted seed-coat color (*i*)	66	18	27	8	1.874	.50– .70
Oval leaflet (*o*) vs. green cotyledon color (d_1d_2) [2]	78	6	33	2	1.363	.70– .80

[1] F_3 ratios.
[2] Theoretical independence ratio, 45:3:15:1.

LEAFLET SHAPE AND PUBESCENCE COLOR

The genes *Tt* for tawny and gray determine the pubescence color of soybeans (*2*). The F_2 ratios (table 8) from four crosses indicate that the *Tt* locus is not linked with those for leaflet shape.

Two normal-gray × narrow-tawny crosses produced F_2 ratios with P values of 0.05–0.10 and 0.10–0.20 when tested against a 9:3:3:1 ratio.

An oval-gray × normal-tawny cross produced an F_2 population with a P value of 0.50–0.70, indicating independent inheritance (table 8).

The 250 segregates of an oval-gray × narrow-tawny cross were tested against the theoretical independence ratio of 27 normal-tawny: 9 normal-gray: 9 oval-tawny: 3 oval-gray: 12 narrow-tawny: 4 narrow-gray. The P value of 0.20–0.30 indicated independence of the genes involved.

NARROW LEAFLET AND FASCIATION

The fasciated character is recessive and the gene is designated *f* (*5*). Six of the F_3 populations of cross 480 segregated for both normal and narrow leaflet-shape and normal and fasciated stems. That these two characters are not linked is shown in table 8 by the P values for each of the six populations, ranging from 0.20–0.30 to 0.98–0.99.

NARROW LEAFLET AND SEED-COAT COLOR

The genes *Gg* for green and yellow determine seed-coat color (*8*). A cross narrow-green × normal-yellow produced an F_2 ratio with a χ^2 value of 8.677, P=0.02–0.05, when tested against a theoretical independence ratio. When this χ^2 value was separated into its com-

ponent parts (*1*), it was noted that the χ^2 value for the *Gg* segregation was the major component, 5.548. The χ^2 value for linkage of 1.673 indicated that *g* and *na* were not linked (table 8).

OVAL LEAFLET AND EXTENSION OF SEED-COAT COLOR

The multiple allelomorphic series governing the extension of seed-coat color includes i^t which limits color to the hilum and which is allelomorphic to *i* which permits complete seed-coat coloring (*4*). The *P* value of 0.50–0.70 for the F_2 ratio of a cross segregating for normal and oval leaflets and for $i^t i$ indicates lack of linkage of the genes involved (table 8).

OVAL LEAFLET AND COTYLEDON COLOR

The action of the unlinked genes D_1 and D_2 is duplicate, each producing yellow cotyledons (*10*). When tested against the theoretical independence ratio of 45:15:3:1, the F_2 (table 8) of a normal-yellow × oval-green cross has a *P* value of 0.70–0.80, indicating absence of linkage of the genes involved.

DISCUSSION

The F_2 data on crosses between normal- and oval-leaflet strains indicate that these strains differ by a single leaflet-shape gene. The symbols *O* and *o* are suggested for the genes which produce normal and oval leaflets respectively.

Data through F_3 from narrow × oval crosses indicate that the genotypes associated with particular phenotypes are *Na-O-* normal, *Na-oo* oval, *nanaO-* and *nanaoo* narrow. As would be expected if the above hypothesis is correct, all narrow-leaflet F_2 segregates produced only narrow plants in F_3. Likewise three (*NaNaoo*) of the eight oval-leaflet F_2 plants produced only oval plants in F_3, whereas the remaining five (*Nanaoo*) segregated in a 3:1 ratio of oval to narrow. Also, the 3:8 ratio is a good fit to the theoretical 1:2 ratio.

The F_2 seeds-per-pod distributions indicate that this character is governed by many genes, all of which do not contribute equally to the expression of the character. The bimodality evident in the low × intermediate crosses and the suggested bimodality in some of the intermediate × high crosses indicate a few major genes for number of seeds per pod. Also, the F_2 distributions of low × intermediate crosses indicate the action of modifying genes since the values of the modal classes of the two subcurves of these distributions were higher and lower than the means of the low and the intermediate parents respectively.

It is felt that the agreement with a 3:1 ratio of the F_2 seeds-per-pod distributions from all intermediate × low crosses justifies the assignment of symbols to the major genes involved. The symbols *Lo* and *lo* are suggested for this allelomorphic pair. *LoLo* and *Lolo* produce intermediate values and *lolo* produces low values.

F_2 seeds-per-pod distributions of 3 of the 12 crosses between intermediate and high parents showed a tendency toward bimodality which is in agreement with Takahashi's (*6*) conclusion that the 2 types of parents differ by a single gene. Takahashi assigned symbols *Ff*

to the allelomorphic pair. It is not known whether the genes involved in the present study are the same as those in Takahashi's material. Neither his symbols nor new symbols are used here since not all of the crosses between normal and narrow parents exhibited the bimodal F_2 distributions. The nearly significant negative correlation coefficient obtained when F_2 values from cross 480 were correlated with their respective F_3 coefficients of variability suggests that the F_2 plants with the higher values were more nearly homozygous with respect to seeds-per-pod genes than those with lower values. If a single major gene pair is involved, F_2 genotypes *aa* would produce high F_2 values and little variability in F_3, F_2 genotypes *AA* and *Aa* would both produce lower F_2 values than *aa* but in F_3 *AA* would produce little variability and *Aa* would produce much variability. The negative correlation mentioned above might have been greater if it were not for the homozygous low seeds-per-pod genotypes *AA* and their respective slightly variable F_3's.

Data from crosses 527, 529, and 511–523 on linkage intensity between high seeds-per-pod and narrow leaflet indicate approximately 9 percent crossing over as compared with 10 percent obtained by Takahashi (*6*).

The question naturally arises as to whether or not the major seeds-per-pod genes form a multiple allelomorphic series. That is, are the gene for an intermediate number of seeds per pod, which is allelomorphic to the recessive high seeds-per-pod gene, and *Lo* the same gene? The following facts suggest that such is not the case. The genes *o* and *na* are both linked with a gene for intermediate seeds-per-pod value with 8 and 9 percent over respectively. If there is only one gene for an intermediate number of seeds per pod, then *o* and *na* would be linked, with either 1 or 17 percent crossing over, approximately, depending on the order of the loci on the chromosome. The χ^2 test was applied to F_2 ratios from the narrow $\times$ oval crosses, testing their fit to both a theoretical linkage ratio with 17 percent crossing over and the ratio for independent inheritance. The *P* values obtained were 0.05–0.10 for the linkage ratio and 0.50–0.95 for the independence ratio; the *P* value for linkage with 1 percent crossing over would be extremely small. It appears therefore that *na* and *o* are not linked and that the dominant intermediate genes that are allemorphic to both *lo* and the high seeds-per-pod gene are not one and the same gene.

Of special interest in this study has been the association of each of two variations (possibly mutations) from the normal leaflet shape with different genes for number of seeds per pod. In one linkage group the oval-leaflet gene *o* is closely linked with the major gene *lo* for low number of seeds per pod. Likewise, in another linkage group the narrow-leaflet gene *na* is closely linked with the major gene or genes for high number of seeds per pod. The quantitative character, number of seeds per pod, seems to be governed by several genes which are not equal in their manifestation. It appears that a very few major genes in association with numerous minor genes are responsible for the expression of that character.

SUMMARY

Data on the inheritance of number of seeds per pod and leaflet shape in the soybean were obtained from 26 crosses between parents with mean seeds-per-pod values ranging from 1.05 ± 0.01 to 3.59 ± 0.03 and with either ovate (normal), lanceolate (narrow), or oval terminal leaflets. One parental variety was characterized by oval leaflets and a very low mean seeds-per-pod value. Three varieties had narrow leaflets and very high mean seeds-per-pod values. The remaining parental types had normal leaflets and somewhat intermediate seeds-per-pod means, all of which differed significantly.

The data indicate that number of seeds per pod, while somewhat influenced by environmental conditions, is largely governed by a few major and several minor genes. The symbols *Lo* and *lo* are suggested for one allelomorphic pair of major genes. *Lo* exhibits considerable dominance over *lo* and produces an intermediate seeds-per-pod value; *lo* produces a low seeds-per-pod value. Certain of the data suggest the existence of a major recessive gene which produces a high seeds-per-pod value as contrasted with an intermediate value produced by its dominant allelomorph.

Plants with oval-shaped terminal leaflets differ from plants with normal leaflets by one leaflet-shape gene. The symbols *O* and *o* are suggested for this allelomorphic pair. *OO* and *Oo* produce normal leaflets and *oo* produces oval leaflets.

Data from the normal-leaflet×narrow-leaflet crosses substantiated earlier reports that a single gene difference is involved. *NaNa* and *Nana* produce normal leaflets and *nana* produces narrow leaflets.

The F_1 plants of crosses between narrow-leaflet plants and oval-leaflet plants had normal leaflets and the F_2 population segregated in a 9 normal: 3 oval: 4 narrow ratio. The genotypes associated with particular phenotypes are *Na-O-* normal, *Na-oo* oval, *nanaO-* and *nanaoo* narrow. The gene *na* is therefore epistatic to *o*.

The locus of the oval-leaflet genes *Oo* is linked with the locus of the genes *Lolo* for number of seeds per pod with approximately 8 percent crossing over. The locus of *Oo* is not linked with the loci of the genes for flower color W_1w_1, pubescence color *Tt*, cotyledon color d_1d_2, or extension of seed-coat color *i* and its allelomorphs.

The locus of the narrow-leaflet genes *Nana* is closely linked with the locus or loci of genes for high number of seeds per pod. It is not linked with the loci of the genes for flower color W_1w_1, pubescence color *Tt*, fasciation *Ff*, or seed-coat color *Gg*.

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A STATISTICAL STUDY OF THE RELATIONS BETWEEN FLAX FIBER NUMBERS AND DIAMETERS AND SIZES OF STEMS [1]

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INTRODUCTION

Relatively few anatomical investigations have been made in the United States to determine the relation between the number and magnitude of fibers in cross sections of the flax stem and the size of the stem. Research in this aspect of the flax problem has been confined chiefly to the continent of Europe and the British Isles.

The object of this study was to obtain a measurement of fibers in flax stems grown in Georgia with a view to making comparisons with similar investigations conducted in other regions.

The investigation has been confined to a determination of the number and diameters of fibers in median cross sections; that is, in sections cut from the middle of the stem at right angles to the length. These stems, selected at random, were of different sizes. The relationships between these fiber characters and stem diameters and median areas have also been determined. No attempt has yet been made to correlate the differences with either environmental or hereditary factors, except in a comparison of two varieties.

Most of the previous studies place the diameter of the stem along with the height in first place in providing an indication of the number and size of fibers per stem. Of these the cross section seems the more important; as height, with the exception of the ends, only adds to what one discovers in the section.

Differences of mineral nutrients, of spacing, or of soil have in most cases been shown to affect the fiber count only indirectly by increasing or decreasing the stem size. The results of a statistical study of cross sections of southern-grown flax should, then, establish a basis for some additional investigations for regional agronomic practices and plant breeding, as well as for linen processing, by demonstrating the types of stems with maximum fiber content. Such knowledge is necessary at this time because of the present interest in the Southeastern States in flax production for both fiber and seed.

REVIEW OF LITERATURE

Davin and Searle (*1*),[2] working with flax in Northern Ireland, obtained a high parent-progeny correlation in flower color, time of flowering, percentage of fiber, length of unbranched part of stem, and possibly number of seeds per capsule. They also found that such

[1] Received for publication June 18, 1943. This investigation has been carried on cooperatively by the Tennessee Valley Authority, Georgia State Engineering Experiment Station, Georgia Agricultural Experiment Station, and the College of Agriculture. Journal Paper No. 116 of the Georgia Agricultural Experiment Station.

[2] Italic numbers in parentheses refer to Literature Cited, p. 281.

characters as diameter, area of stem, size of fiber, area of fiber, number of fibers, fibers per square millimeter, number of capsules, and seeds are strongly influenced by environment, and show no significant correlation with those of the parent.

Previous writers have found that the largest array of the most representative fibers is in the median area of the stem. Distal sections show fewer and less developed ones, and sections cut at the crown or below contain only a small number of very coarse fibers. Herzog (*3*), from an average of 25 stems, found 55 fibers in basal sections, 550 in stems at a height of 25 cm., 530 at 50 cm., and 320 at 75 cm. Tammes (*8*) found that the number of fibers in cross section does not vary much in a single stem except at the lower and upper parts. For these reasons Tammes, Robinson (*6*), and Davin and Searle (*1*) all used the fibers from median sections in distinguishing the fiber differences in flax stems of different varieties or of those grown under different environmental conditions.

The characters found to be influenced largely by environment, that is, size of stems, number of fibers per stem, number of fibers per bundle, number of bundles per stem, number of fibers per unit-section areas, and size of fibers, have been shown to be correlated. Tammes (*8*) found an increase in number of fibers with increasing diameters of stems up to 2.6 mm., but did not obtain the same proportionate increase in number of fibers in larger stems. Robinson (*6*) and Davin and Searle (*1*) also obtained a noticeable increase in the number of fiber cells per section with an increase in stem diameter.

The number of bundles in median cross section has been found by most writers to vary somewhat with the diameter of the stem. Tammes (*8*) has shown that the number of bundles increases with the thickness of the stems, but is more constant in thick stems than in thin ones. Davis (*2, p. 4*), on the other hand, says: "The average number of fiber bundles is not materially less in a stem of small diameter . . ." Tammes (*8*) reported that the number of fibers per bundle in stem cross section varies with different stem diameters and is higher in the thicker stems. Davis (*2*) states that the fiber bundles are necessarily smaller in fine stems as they are crowded together into a smaller girth of cortex.

The numbers of fibers per square millimeter of median stem area has been shown to vary in inverse proportion to the stem thickness. Davin and Searle (*1*) show an almost constantly decreasing fiber number per unit area with increasing thickness of stems for the Dutch variety. Small stems of the 0.75-mm.^{2} class have a mean of 412.5 fibers; and the large class, 14.25-mm.^{2}, have 87.5 fibers per square millimeter. Robinson's (*6*) data show that the average of his small stems grown in tap water only, 0.678 mm. in diameter, contained 259 fibers per square millimeter, whereas his larger stems grown in N–2P–K solution averaged 1.176 mm. in diameter and contained only 139 fibers per square millimeter.

That diameters of the fibers increase with increased thickness of the stems has been shown by Tammes (*8*), who reported a large positive correlation. She found no direct influence of the soil on diameter of the fiber except that when seeds were sown far apart there were larger stems and so larger fibers. Davis (*2*) and Davin and Searle (*1*) also found that a thin stand produces larger stems and therefore larger fibers.

MATERIALS AND METHODS

The flax straw for the 420 stems used in most of the experimental work was chiefly from the variety Cirrus, a fiber flax; that used for the comparison of varieties was from strains of Cirrus and Triumph. The flax was grown in Brooks County, Ga. It was sown in the fall and harvested the following June. The soil on which it was grown was chiefly Norfolk sandy loam. A complete fertilizer was used at planting, followed by a top dressing with nitrate of soda in the spring.

The flax plant, although normally self-fertilized, does hybridize to some extent. If that cause of variation is added to the mixing that occurs at harvest and in the preparation for distribution, it may be concluded that the usual commercial variety is both a genetical and mechanical mixture of many diverse homozygous strains as well as heterozygous individuals. The flax stems used in this investigation constitute such a mixture, and therefore it would appear that the variations are in part hereditary and in part purely environmental. The fiber characters of stems of different diameters that are discussed in this paper are such as have previously been found to be influenced chiefly by environment, whereas those of stems of the same diameter are influenced more by hereditary factors and can be the basis for future selections.

The stems were brought into the laboratory when completely mature. At first cross sections were made from median portions embedded in celloidin, but this procedure was found to be too slow, and a more rapid method of hand sectioning was devised. Median stem parts, about 2 inches in length, were boiled in water for about 2 minutes to force out the air and soften the stem. They were then taken out and embedded in paraffin in groups of fives. When the paraffin hardened, the blocks were cut down through the ends of the stems and placed in water for several days. After this soaking, cross sections were readily cut by hand with a safety-razor blade. Sections were then mounted in glycerin. Counting fibers and bundles was accomplished both by direct view through the microscope and by projection on a screen.

EXPERIMENTAL RESULTS

RELATION OF NUMBER OF FIBERS PER MEDIAN SECTION TO STEM DIAMETER

The 420 stems that formed the basis of this study have a mean diameter of 1.63 ± 0.021[3] mm., with a standard deviation of 0.43 ± 0.015 mm. About 89.5 percent of them lie between 1 and 2.19 mm. in diameter (table 1). The unusually large or extremely small classes of stems are not represented.

The number of fibers per stem section ranges from 125 to 1,375, with 85 percent falling between 300 and 799 (table 1). The mean for the group is 538 ± 8.807, with a standard deviation of 180.40 ± 6.242 fibers. This is not an unexpectedly large variation when the wide range of stem sizes is considered.

The correlation between the fiber numbers and the stem diameters (fig. 1) is highly significant, with a coefficient of $+0.719 \pm 0.024$. An r value of 0.128 is at the 1-percent level of significance according to Snedecor's (7) table.

[3] Standard error.

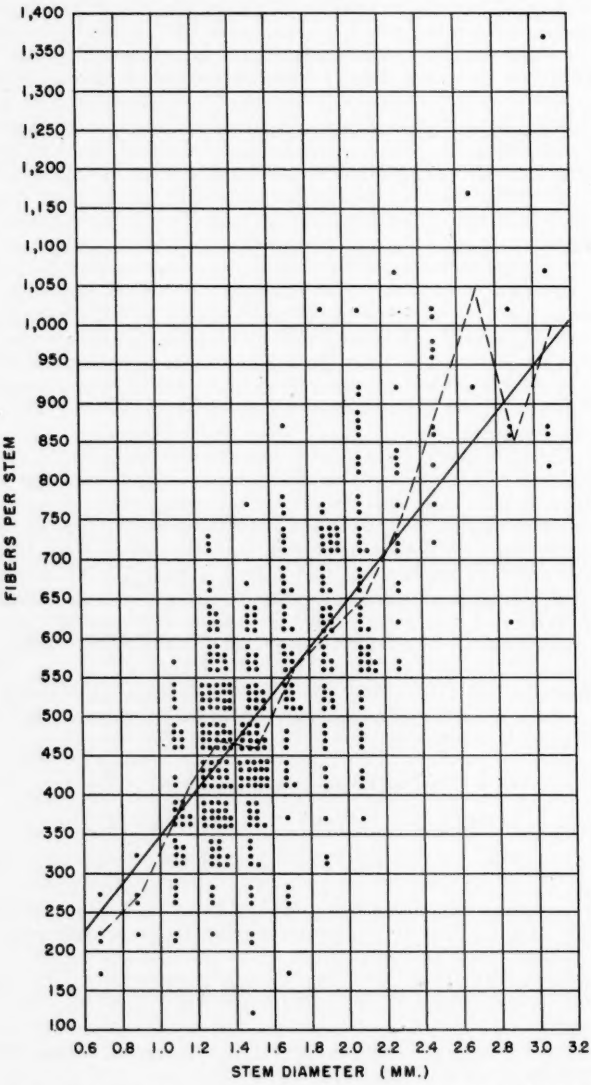

FIGURE 1.—Relation between numbers of fibers per stem and diameters of 420 flax stems.

TABLE 1.—*Proportion of the 420 flax stems studied that fall within each diameter class, fiber-number-per-stem class, fiber-bundles-per-stem class, fibers-per-bundle class, stem-area class, and fibers-per-square millimeter class*

Stem diameters		Fibers per stem		Fiber bundles per stem		Fibers per bundle		Stem areas		Fibers per mm.²	
Range	Proportion within length range	Range	Proportion within specified range	Range	Proportion within specified range	Range	Proportion within specified range	Range	Proportion within specified range	Range	Proportion within specified range
Mm.	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Mm.²*	*Per cent*	*Number*	*Per cent*
0.6–0.99	1.91	100–199	0.71	10–19.9	3.81	10–14.9	22.38	0–0.9	9.76	0– 99	0.71
1.0–1.39	35.24	200–299	5.71	20–24.9	17.38	15–19.9	43.57	1–1.9	46.90	100–199	18.10
1.4–1.79	30.71	300–399	15.48	25–29.9	35.24	20–24.9	23.10	2–2.9	23.33	200–299	40.00
1.8–2.19	23.57	400–499	24.05	30–34.9	28.33	25–29.9	7.62	3–3.9	13.33	300–399	23.57
2.2–2.39	5.95	500–599	23.33	35–39.9	12.62	30–34.9	2.14	4–4.9	4.05	400–499	13.57
2.4–2.79	1.43	600–699	12.86	40–55.0	2.62	35–45.0	1.19	5–5.9	.48	500–599	3.33
2.8–3.20	1.19	700–799	9.29					6–8.5	2.14	600–700	.71
		800–899	4.76								
		900–1, 099	3.33								
		1, 100–1, 400	.48								

The straight line in figure 1 represents a regression of 301.64 ± 14.204 fibers for every increase in stem diameter of 1 mm., or an increase of 60.33 fibers for each 0.2 mm. increase. The error of the estimate is 125.52, and the regression coefficient is highly significant with a t value of 21.2, when 2.588 is at the 1-percent level (*7*).

Figure 1 shows that the prediction line is a very good fit for the X means of the Y columns up to the 2.3-mm. class of stems, and that the distribution in this area is definitely linear. However, an analysis of variance of the entire distribution shows an F value of 2.84 for nonlinearity, when 1.81 is at the 5-percent point of significance. In spite of this it does not seem worth while to plot a curve when 90 percent of the stems fall within an area best fitted by a straight regression line. Then, again, the relatively few large stems would probably cause the calculated values of a curve to be of little value in estimating fiber numbers of other stems of those sizes.

According to the results given above, 51.7 (r^2) percent of the variation in fiber number is accounted for by the variation in stem diameter.

Authors previously referred to have determined that the effect of environment is chiefly to produce larger or smaller stems, and so to increase or decrease the number of fibers. Stems of the same diameter class would then have been grown under approximately the same environment, and the wide variation in fiber numbers in such classes could be attributed to hereditary factors. For example, in stems in the 1.9-mm. class, included in those on which data are given in figure 1, there was one with 1,025 fibers and two with only 325 fibers. This suggests the possibility of isolating superior strains.

None of the authors cited in this paper worked correlation tables between fiber numbers and stem diameters. However, Tammes (*8*) shows that there is a gradual increase in fibers beginning with stems 0.55 mm. in diameter containing 188 fibers per cross section and continuing up to stems 2.2 mm. in diameter with 1,110 fibers per cross section. The mean diameter of stems studied by her, both large and small, was 1.63 mm. and the mean fiber number was 696. The mean

diameter of stems measured by Tammes was about the same as that of the 420 stems used in the present work, but the mean fiber number was much larger than that of the Georgia-grown stems.

Davin and Searle (*1*) did not calculate the means of stem diameters or of fiber numbers, but in the 1.69-mm. diameter class studied by them the mean fiber number is 681.97. This number is about the same as that found by Tammes for stems of that diameter. The mean of the 1.69-mm. class in the Georgia experiments is about 100 fibers less (fig. 1); however some of the stems in this class contained many more fibers.

RELATION OF NUMBER OF FIBER BUNDLES PER MEDIAN SECTION TO STEM DIAMETER

The sections of the 420 stems used in the study to determine the number of fibers were also employed in a study to determine the number of fiber bundles. In most of the sections the bundles of fibers were quite distinct and were sharply separated by parenchyma cells, but in a few the fibers formed an almost continuous layer.

The number of fiber bundles ranged from 10 to 55, 93.57 percent of the stems containing from 20 to 39.9 bundles (table 1). The mean number of bundles was 29.34 ± 0.277 and the standard deviation was 5.72 ± 0.197 for the mean stem diameter of 1.63 mm.

A significant positive correlation is found between number of bundles and stem diameter, with a coefficient of $+0.396 \pm 0.042$ (fig. 2) when the 1-percent point is 0.128.

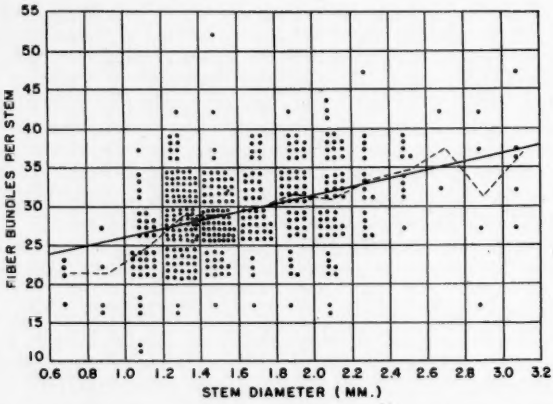

FIGURE 2.—Relation between number of fiber bundles per stem and stem diameter

The number of bundles, shown by the regression line in figure 2, increases 5.32 ± 0.585 for each increase in stem diameter of 1 mm., or an increase of 1.06 for each 0.2 mm. of stem increase. The standard error of the estimate is 5.265, and the t value shows a highly significant coefficient of 8.80 when 2.588 is at the 1-percent level.

An analysis of variance to test for nonlinearity shows an F value of 1.85 when 1.81 is at the 5-percent point. This distribution constitutes a borderline case, but an inspection of the chart shows that a straight line represents the relationship very well throughout most of the population.

Only 15.68 percent of the variability of the number of bundles per stem can be considered as associated with the differences in stem sizes. The larger stems, accordingly, have a somewhat greater number of bundles than the smaller ones, but this increase is not so marked as in the case of number of fibers.

The range of fiber bundle frequency in stems of the same diameter classes, as shown in figure 2, is almost as great as that of the fibers per stem in figure 1. This variation seems sufficient for isolating lines with selected bundle numbers.

Tammes (*8*) in table 24 of her publication, which gives data on 46 stems of various diameters with a mean of 1.63 mm., shows the mean number of bundles per stem to be 30.37. This number is nearly the same as that found in this investigation.

RELATION OF NUMBER OF FIBERS PER BUNDLE IN MEDIAN SECTION TO STEM DIAMETER

There are two ways in which the number of fibers per bundle may vary. The first type of variation arises from the fact that the bundles in the longitudinal section are elongate-spindle in form, and so apical sections of the bundle will always show few fibers and the maximum number will be in the bundle center. Each stem cross section, therefore, will contain a few extremely small bundles interspersed with larger ones. The second type of variation is found between stems, when the mean number of fibers per bundle in one stem is much smaller or larger than in another. Both types of variation are included in the results of this study.

The average number of fibers per bundle in the 420 stems studied ranged from 10 to 45, 89.04 percent having between 10 and 26 fibers per bundle (table 1). The mean number was 18.87 ± 0.253 with a standard deviation of 5.22 ± 0.181 for the mean stem diameter of 1.63 mm.

There is a highly significant positive correlation between the number of fibers per bundle and the stem diameters (fig. 3). The coefficient is $+0.539 \pm 0.035$. The r value at the 1-percent level is 0.128 as in the previous parts.

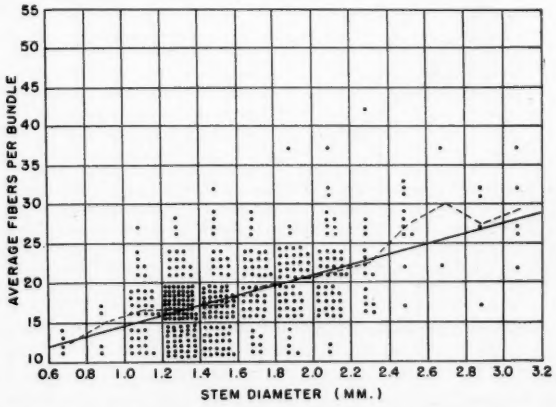

FIGURE 3.—Relation between average number of fibers per bundle and stem diameter.

The straight line in figure 3 shows a regression of 6.54 ± 0.496 fibers per bundle for each increase of 1 mm. in stem diameters; or for each increase of 0.2 mm. in stem diameter there is a corresponding increase of 1.31 fibers per bundle. The error of estimate is 4.41, and the coefficient is highly significant as there is a t value of 13.04 when the 1-percent level of significance is 2.588. The test for nonlinearity by analysis of variance shows an F value of 1.404 when 1.81 is at the 5-percent level of significance; hence there is no evidence of nonlinear regression.

As the stem diameters increase the average fiber number per bundle increases, and 29.05 (r^2) percent of the variation in this fiber number increase may be ascribed to increase in stem thickness.

Tammes (*8*, *table 24*) shows a mean number of fibers per bundle of 22.92 for 46 stems. This figure is somewhat higher than the 18.87 fiber number found in the Georgia stems.

RELATION OF NUMBER OF FIBERS PER SQUARE MILLIMETER IN MEDIAN SECTION TO STEM AREA

Davin and Searle (*1*) use the term "fiber index" to designate the number of fibers per unit area. The fiber index is obtained by dividing the area of each stem cross section into the number of fibers.

The areas of the 420 stem sections included in this study range from 0.25 to 8.5 mm.^{2}, with 83.57 percent between 1 and 3.9 mm.^{2} The mean stem area is 2.14 ± 0.061 mm.^{2}, with the standard deviation $1.240. \pm 0.043$.

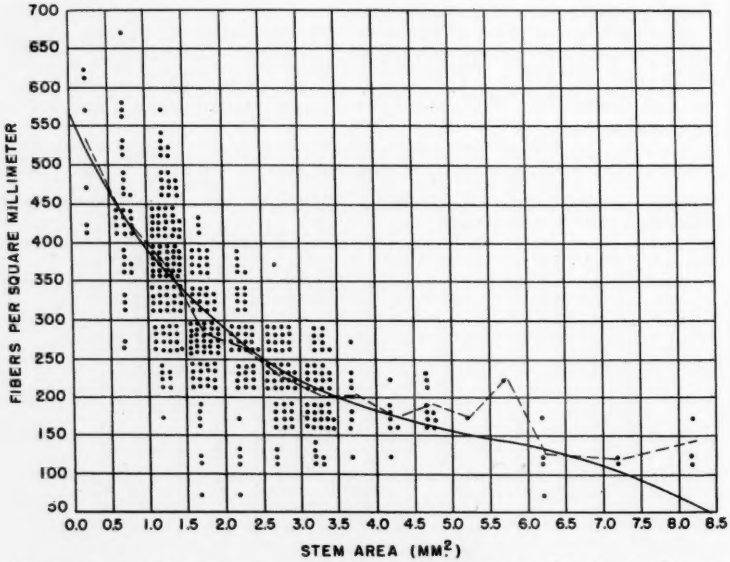

FIGURE 4.—Relation between number of fibers per square millimeter and area of stem in the median cross section.

The number of fibers per square millimeter (table 1) ranges from 50 to 700, 95.24 percent of the stems having between 100 and 499. The mean number of fibers for the 420 stems is 295.70 ± 5.183, with a standard deviation of 106.20 ± 3.674.

A negative correlation was found between the number of fibers per square millimeter and the area of the stem section (fig. 4). The coefficient -0.678 ± 0.027 is highly significant, as the 1-percent level of significance is 0.128.

The regression here is not linear, but fits the curve $X=A+BT_1+CT_2+DT_3$, as given by Love (*4*), except at the lower end. This curve, as shown in figure 4, follows the broken line connecting the X means of the Y columns very closely throughout the blocks of densest population. Table 2 presents in tabular form= what is shown graphically by the curved regression for numbers of fibers per square millimeter for each stem-area class in figure 4. The coefficients are: $A=215.5$ fibers, $B=23.5$, $C=1.71$, and $D=0.208$. As the stem increases in area the fiber number decreases, but not in uniform proportion.

TABLE 2.—*A comparison of the mean number of fibers per square millimeter in stems of different areas and the predicted values for each stem class*

Classes of stems by areas (sq. mm.)	Means of fiber numbers per square millimeter	Predicted values for curved regression line for fiber numbers per square millimeter	Classes of stems by areas (sq. mm.)	Means of fiber numbers per square millimeter	Predicted values for curved regression line for fiber numbers per square millimeter
0.25	525	506.44	4.75	190	161.64
.75	435	431.24	5.25	175	150.72
1.25	370	368.16	5.75	225	140.72
1.75	283	315.98	6.25	125	130.36
2.25	265	273.44	6.75	0	118.42
2.75	226	239.29	7.25	125	103.64
3.25	203	212.28	7.75	0	84.76
3.75	200	191.16	8.25	142	60.56
4.25	175	174.70			

In the test of goodness of fit of this curve on the X mean of each stem column there is a χ^2 of 378.84 for the entire curve, indicating a poor fit, but if one stops with the 4.25 stem class χ^2 is only 5.98. The cubic parabola is a good fit for the distribution up to the maximum point of the curve. This curve includes 95 percent of the stems and has a P value, according to Pearson's (*5*) table, of 0.649438. As was found earlier in the study of the relation of number of fibers per median section to stem diameter, the larger stems do not appear to follow the law governing the smaller ones.

The variability of fiber number per square millimeter associated with the variation in the areas of the stem is 45.97 percent (r^2).

Davin and Searle (*1, table XVI*) have reported for small stems of the Dutch variety, 0.5 to 1 mm.^{2} in area, 412.5 fibers per square millimeter; and for large stems, 7 to 7.5 mm.^{2} in area, 128 fibers per square millimeter. The Georgia-grown stems of equal area have means of 435 fibers per square millimeter for the small stems and 125 fibers for the large ones. This bears out the tendency referred to above for fiber index to decrease with increasing stem size.

These results show that the medium size stems, or even the smaller ones, of equal height have fewer fibers per stem but more per unit area of cross section than larger ones. In equal volumes of small and large stems the small stems would produce the greater number of fibers.

RELATION OF FIBER DIAMETER TO SIZE OF STEMS

The diameters of 50 consecutive fibers in each cross section of the ten smallest stems of the 420 were found and compared with similar measurements of 50 consecutive fibers in each cross section of the 10 largest stems. The difference between the means of the two groups of stems, as shown in table 3, is 31.30 times its standard error. This

TABLE 3.—*Comparison of the diameters of the smallest and largest stems*

Stem class	Range in diameter stems	Mean stem diameter	Standard deviation
	Mm.	*Mm.*	
10 smallest stems	0.65–1.05	0.84±0.039	0.12±0.027
10 largest stems	2.70–3.30	3.00±0.059	0.19±0.041
Difference of meqns		2.16±0.069	

is more significant than the mean fiber diameter difference given in table 4, which is 3.97 times its standard error. These data indicate

TABLE 4.—*Comparison of the diameters of the fibers of the small and large stems in table 3*

Stem class	Range in diameter of fibers	Mean fiber diameter	Standard deviation
	μ	μ	
10 smallest stems	7.2–28.8	17.32±1.466	4.64±1.036
10 largest stems	7.2–72.0	30.98±3.110	9.83±2.199
Difference of means		13.66±3.438	

that as the stem increases in thickness the diameter of the fiber increases, but to a less degree. Large stems in this group would be expected to have coarse fibers not so well adapted for manufacture of the higher grade products.

The relation between stem sizes and fiber diameters of Georgia-grown flax is approximately the same as that of the Netherlands-grown flax reported by Tammes (*8*). Here table 32 shows a mean stem diameter of 0.87 mm. for 14 small stems, which have a mean fiber diameter of about 17μ. The four large stems, with a mean-stem diameter of 3.08 mm., have a mean-fiber diameter of 37.18μ.

COMPARISON OF FIBERS PER SQUARE MILLIMETER IN MEDIAN SECTIONS OF THE FIBER FLAX VARIETIES CIRRUS AND TRIUMPH

Median cross sections of 90 stems of Triumph and 90 stems of Cirrus flax grown in Brooks County, Ga., were made for this study. The sections of Cirrus ranged in area from 0.25 to 4.75 mm.^{2}, with a mean of 1.81±0.085 and a standard deviation of 0.81±0.061. The number of fibers per square millimeter for each stem ranged from 75 to 625, with a mean of 310±10.468 and a standard deviation of 99.25± 7.401.

In this series of sections there is a negative correlation of −0.716± 0.052 between the number of fibers per square millimeter and the stem area. This coefficient is significant, because the 1-percent level of significance of r is 0.267. This is only a slightly larger negative correlation than that found for the 420 stems.

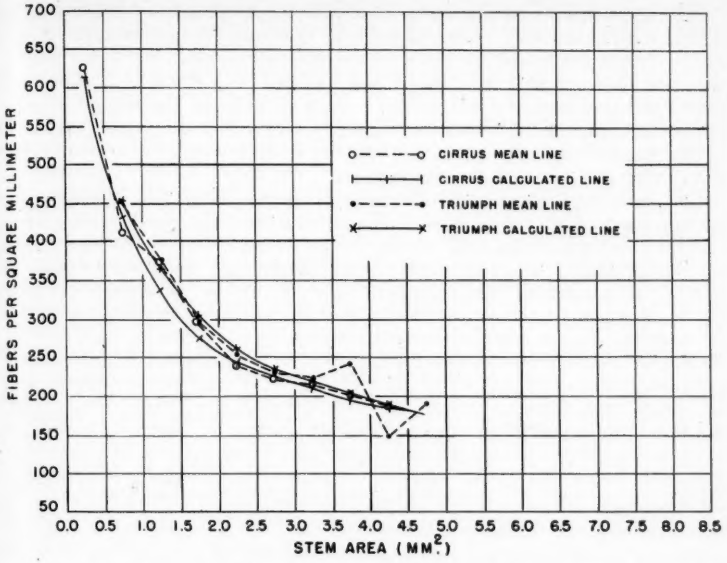

FIGURE 5.—Comparison of the number of fibers per square millimeter and the median-stem areas of Cirrus with those of Triumph flax.

The means of the fibers per square millimeter for each stem-class row for both Cirrus and Triumph are plotted in figure 5 and are connected with broken lines. The predicted values for both varieties are connected with solid lines, and are produced by the same formula used in the study of the relation of fibers per square millimeter to stem area. The one unusually large stem in the 4.75-mm.^{2} class found in this random sample of Cirrus is not considered in the curve, as a calculated value based on one stem would have little significance. The curve values for A, B, C, and D are 337.8, 61.7, 15.0, and 2.4, respectively.

The test of goodness of fit of the curve on the X means of the Y columns shows a χ^2 of 6.681 with a P value in Pearson's (*5*) table of 0.353494.

Within these Cirrus stems 51.3 percent of the variability of the fiber number per square millimeter is associated with the variation in the median stem areas.

The stems in the Triumph variety ranged from 0.5 to 7.5 mm.^{2} in area, with a mean of 2.27 ± 0.129mm.^{2} and a standard deviation of 1.22 ± 0.090.

The fibers per square millimeter ranged from 125 to 450, with a mean of 292.20 ± 10.107 and a standard deviation of 95.83 ± 7.128. There is also a negative correlation between the number of fibers per square millimeter and the stem areas. The coefficient -0.700 ± 0.053 is significant, as the r value at the 1-percent level of significance is 0.267, as with Cirrus.

The Triumph curve is based on the values of A, B, C, and D, which are respectively 269.6, 31.1, 4.8, and 8.4.

The goodness of fit for this curve shows a χ^2 value of 17.822 for the total, which indicates that the fit is not highly significant. Here, again, the cubic parabola fits the first six classes with 90.91 percent of the population very well, with a χ^2 of 0.768 having a P value of 0.962566 in Pearson's (δ) table. As was true in the other studies involving number of fibers per square millimeter, the larger stems in these random samples are too few to be expected to follow a law governing the mass of the population.

In the Triumph variety 49 percent of the variability in fiber number per square millimeter is associated with the variation in the stem areas.

The Triumph stems with a mean of 2.27 mm.^{2} were larger than those of Cirrus with a mean of 1.81 mm.^{2} There was also more variation in the stem sizes of the Triumph (table 5). The difference between the means is 3.01 times its standard error, which is significant.

TABLE 5.—*A comparison of the median areas of 90 stems of the Cirrus variety with 90 of the Triumph variety*

Variety	Range in stem areas	Mean stem area	Standard deviation
	Mm.^{2}	*Mm.*^{2}	
Cirrus	0.25–4.75	1.81±0.085	0.81±0.059
Triumph	0.50–7.50	2.27±0.127	1.22±0.090
Difference of means		0.46±0.153	

TABLE 6.—*A comparison of the number of fibers per square millimeter of the median areas of 90 stems of the Cirrus variety with 90 of the Triumph variety*

Variety	Range in number of fibers per mm.^{2}	Mean number of fibers per mm.^{2}	Standard deviation
Cirrus	75–625	310.0±10.467	99.25±7.416
Triumph	125–575	292.2±10.107	95.83±7.143
Difference of means		17.8±14.550	

The mean number of fibers per square millimeter is greater in the Cirrus variety, 310, than in the Triumph with 292.2. This difference is due to the fact that Triumph has larger stems than Cirrus. However, table 6 shows that the difference between the means of the number of fibers per square millimeter is only 1.22 times its standard error, which is not significant.

The correlation between fibers per square millimeter and stem areas is nearly the same, −0.700 for Triumph and −0.716 for Cirrus.

The mean lines in figure 5 show that between the 0.75-mm.^{2} and the 3.25-mm.^{2} classes the mean fiber numbers for the two varieties are almost the same. Cirrus and Triumph stems of equal size, therefore have approximately the same number of fibers per square millimeter of median section. There are, however, other material differences, such as the greater amount of top branching and formation of seed, in the Triumph.

SUMMARY

This study of the relation of flax fiber numbers and diameters to stem sizes in Georgia-grown flax has been made with median or midsections cut from stems selected at random.

The fibers in the median portion of the stem are both more uniform and more numerous than those at the top or bottom.

Cross sections of 420 stems show that as the stem increases in diameter the number of fibers, the number of bundles, and the number of fibers per bundle increase. The correlation is greatest between fiber number and stem thickness. The exceptionally large stems do not exhibit the same degree of linearity of regression as those of medium or smaller diameter.

A negative correlation was found between the number of fibers per square millimeter and the cross-section area of the stem. Large stems have fewer fibers per unit of area than small stems. In this case the regression is nonlinear and again the calculated values for the few very large stems are not worth as much for prediction purposes as those of the rest of the population.

Large stems have coarser fibers than small stems. Diameters of fibers in the 10 largest stems are nearly twice those of the 10 smallest.

A comparison of Cirrus with Triumph, two fiber varieties, shows that the fiber number per unit area of cross section is practically the same in stems of equal size, but as the average diameter of Triumph is larger, the fibers per square millimeter are fewer.

A comparison of fiber numbers per stem section of equal diameter of Georgia flax with published results from the Netherlands and Northern Ireland shows a reduction of about 20 percent in the former.

A study of the correlation charts in this paper shows that within flax stems of equal diameter the range of fiber and bundle numbers is probably wide enough to provide a basis for single-plant selections.

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